

Application of Hydrocarbon Fuel Conversion in Aircraft Engines

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Abstract—Issues pertaining to the use of hydrocarbon-fuel conversion processes for cooling heat-loaded parts of aircraft engines are briefly considered. A setup intended for testing thermochemical reactors operating as elements of thermal protection is described. Results of experiments with methane conversion on various catalysts and data on the consumption of a chemically reacting mixture and the temperature of heated reactor walls are presented.

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In recent years, considerable effort expended on developing new types of aircraft and spacecraft technologies in leading countries has been devoted to basic problems of the creation of hypersonic flying vehicles (HFVs) for speeds of up to $M = 6-8$ [1]. To do this, engines developed for HFVs must possess high thrust and efficiency characteristics at relatively low weights. At the present stage of research, the main types of engines designed for HFVs are of the air-breathing (ramjet/scramjet) type with hypersonic airflow in the combustion chamber, which provides for the maximum possible specific impulse in the desired speed range.

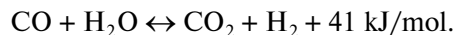
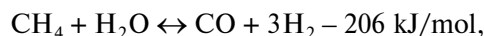
Use of the hydrocarbon fuel-conversion process for cooling heat-loaded parts of high-speed flying vehicles and ensuring stable fuel combustion in supersonic airflow has been considered by specialists since the 1960s [2, 3].

The recent flight of the Boeing X-51 scramjet showed that it is possible to create an HFV working on hydrocarbon fuel [4]. Active thermal protection of the engine in the X-51 was provided by carrying out cracking of JP-7 fuel in the cooling jacket, after which the products were fed into the combustion chamber.

In addition to the process of hydrocarbon-fuel cracking, steam reforming conversion is a possible candidate for the endothermal cooling process onboard an HFV. This catalytic reaction exceeds cracking in the magnitude of endoeffect and hydrogen yield [5], which makes it possible to further increase the flight Mach number and ensure stable combustion of hydrocarbon fuel in the engine.

In this work, the hydrocarbon fuel was methane representing the main component of liquid hydrocarbon gasification. In addition, the use of methane in the

hydrocarbon steam conversion reaction allowed us to estimate the ultimate possibilities of a thermochemical reactor (TCR) as a means of thermal protection by evaluating the amounts of utilized heat and obtained hydrogen. The equilibrium composition of methane steam reforming conversion is determined by two reversible reactions:



A TCR (Fig. 1) comprises two channels 1 with a length of 590 mm, a width of 60 mm, and a height of 4 mm, which form a cooling jacket of central channel 2 in which a plasma jet heating the inner walls is propagating. The reactor was made of heat-resistant chromium–nickel steel (KhN78T grade). Figure 2 presents a schematic diagram of the experimental setup used for TCR testing. Water was converted into steam in evaporator 1. Steam and methane supplied from a pressure vessel were heated in electric heaters 2 and 3, respectively. The reactants were then mixed and supplied to TCR 4 at a temperature of about 500°C. The reactor walls were heated by the jet from plasmatron 5. The temperature of the inner walls was measured by thermocouples 6. Samples for the analysis of the composition of reaction products were taken by probes 7.

The first series of experiments was carried out in a reactor with smooth walls possessing a natural catalytic activity. At a steam–methane mixture supply rate of $G = 0.7$ g/s and the inner wall temperature of $T_w = 1050^\circ\text{C}$, the degree of methane conversion X did not exceed 6% (Fig. 3). A decrease in the steam–methane mixture supply rate to 0.2 g/s led to an increase in the degree of conversion up to 37% due to the longer time that the reaction mixture was in the reactor. However,

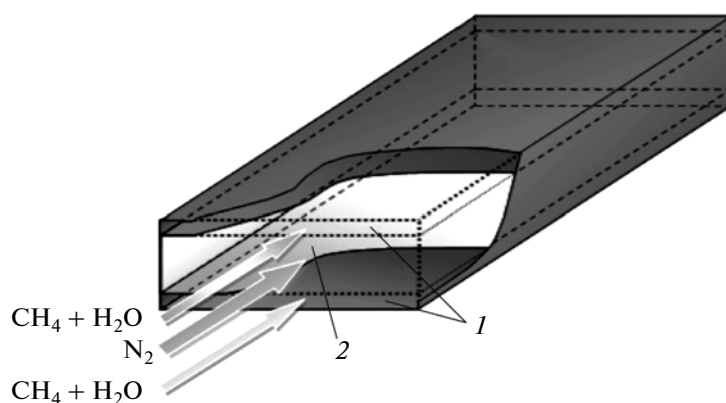


Fig. 1. Scheme of TCR: (1) cooling channels; (2) central channel.

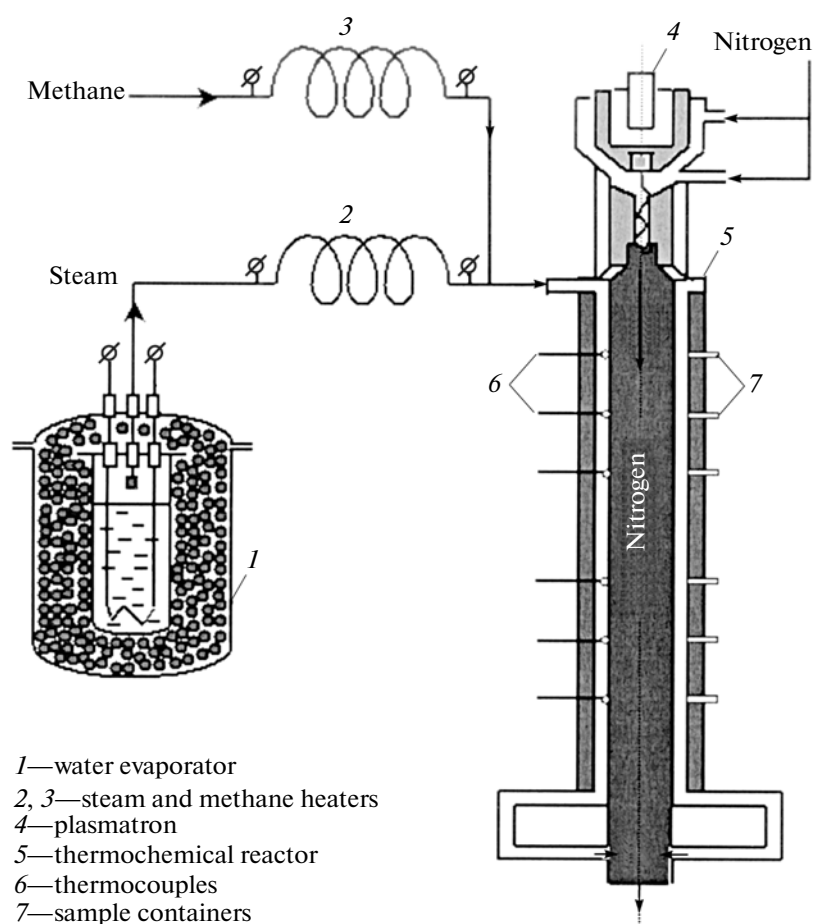


Fig. 2. Schematic diagram of the experimental setup used for TCR testing (see text for explanations).

the situation qualitatively changed in a series of experiments with skeletal nickel catalyst in the form of a pressed wire filling the reactor volume and having good thermal contact with the walls. In this case, the degree of methane conversion at a mixture supply rate of $G = 0.7$ g/s increased to 92%. The hydrogen yield

amounted to 40 vol % at $T_w = 1050^\circ\text{C}$ and increased to 65 vol % at $T_w = 1250^\circ\text{C}$.

Thus, we have established the main factors influencing the degree of hydrocarbon-fuel conversion in a TCR: (i) catalyst type, (ii) rate of reactant mixture consumption, and (iii) temperature of heated walls.

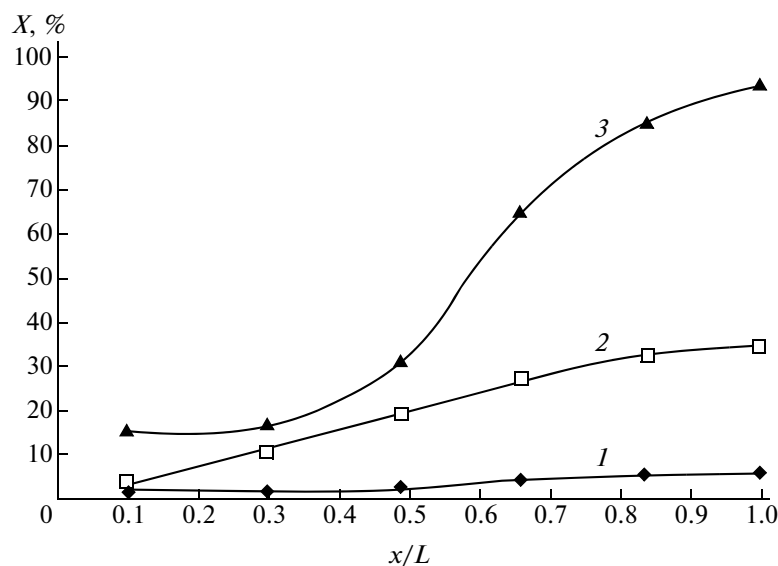


Fig. 3. Variation of degree of methane conversion along the TCR: (1) $G = 0.7$ g/s (smooth wall), (2) $G = 0.2$ g/s (smooth wall), and (3) $G = 0.7$ g/s (skeletal nickel catalyst).

The results of experiments on methane conversion were obtained at moderate thermal flux densities ($q \leq 10^5$ W/m²). In forthcoming experiments, we plan to increase the thermal load up to 10^6 W/m² and above.

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REFERENCES

1. R. V. Bal'mina, A. A. Gubanov, M. A. Ivankin, and D. A. Lapinskii, *Advances in Foreign Science and Technology: Aircraft and Spacecraft Technologies* (TsAGI, Moscow, 2012), Issue 1–2 (1821–1822) [in Russian].
2. H. Lander and A. Nixon, AIAA Paper 68–997 (1968), pp. 1–12.
3. L. Maurice and T. Edwards, *Progr. Astronaut. Aeronaut.* **189**, 757 (2000).
4. www.af.mil/news/story.asp?id=123346970 (retrieval date 03.05.2013).
5. A. L. Kuranov and A. V. Korabel'nikov, *Polet*, No. 6, 8 (2000).

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